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Title of Proposed Observation:

Observational Exploration of the Height Variation of Magnetic Fields and Chromospheric Dynamics In and Above Umbral Dots

Main Objective:

We wish to explore the height dependence of the mangnetic field vector in the deep photosphere of umbral dots, and to search for any chromospheric response to the umbral dot phenomenon.

Scientific Justification:

In order to better understand their convective origin and the role that umbral dots play in the subsurface structure of the sunspot magnetic field and the overall energy balance of umbrae, it is important to have a firm observational description of the magnetic field strength and geometry within and surrounding them. Hinode has been used to explore the structure of umbral dots (Sobotka and Jurčák 2010), with the conclusion that little reduction in the field strength and no change in inclination is seen in measurements using the 630 nm lines of Fe I. This observational result in the 630 nm lines from Hinode was foreseen by Degenhardt and Lites (1993), who constructed a theoretical model of a field-free inclusion (and umbral “flux tube”) within a surrounding strong vertical field. Degenhardt and Lites synthesized not only the 630 nm Fe I lines, but also the 1565 nm Fe I lines. Unlike the visible lines, the synthesized near-infrared 1565 nm lines showed considerable reduction in field strength because they form at somewhat lower layers than their visible counterparts. In view of these theoretical results, we propose to make simultaneous observations of umbral dots in the Fe I lines at 630 nm and 1565 nm, the latter being observed from the ground with the Grating Infrared Spectrograph (GRIS) at the new 1.5 m GREGOR telescope at Tenerife. The aim is to explore the observed variation of the umbral dot magnetic field vector when observed at the heights where these two diagnostic lines form. It should be noted that field diagnostics are very robust because of the large magnetic splitting present in umbrae, and the GREGOR/GRIS combination has proven observational capability for ~0.4 arcsecond resolution at 1.56 microns.

Little is known about any chromospheric manifestation of the umbral dot phenomenon. At chromospheric heights umbrae usually exhibit oscillations with a period around 3 min (“umbral flashes”), but there is little exploration of any specific association of chromospheric dynamics with umbral dots in the photosphere. There is a motivation for such observations from theory: a study by Choudhuri (1986) indicated that the magnetic field above a field-free inclusion (umbral dot) acts as a valve that can be forced open by the piling up of the upflowing plasma inside the low field region. He predicted the formation of

plasma jets above the dot's apex whenever the pressure of the field-free plasma inside the umbral dot exceeds a certain threshold. Recognizing that there has been little exploration of chromospheric dynamics in association with umbral dots, we propose to use the opportunity of the coordinated high-resolution Hinode and GREGOR/GRIS observations to encompass IRIS spectroscopy as well.

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Dates: ToO: Observing run scheduled at GREGOR for 19 August – 1 September 2016. We would like to have a minimum of two successful days of coordinated observations during this period. We estimate that we need 10 days of standby during the GREGOR scheduled observations to await a suitable ToO and to have suitable weather/seeing at the GREGOR telescope.

Time window: Seeing is best in the 08:00 – 10:OO UT window at the GREGOR on Tenerife. We request observations during this period. Short interruptions for synoptic measurements are permissible.

Target(s) of interest: We need a well-developed sunspot umbra within 30 degrees of disk center.

SOT Requests:

The Hinode SOT/SP observations should have the following characteristics:

1. Observations programmed during good seeing hours typical at the GREGOR telescope: 08:00 to 10:00 UT
2. Program run during an upcoming scheduled observing run for this purpose; 19 August – 1 September 2016, and in a later follow-on observing runs (dates TBD) should observations not succeeding due to lack of appropriate solar activity, lack of suitable seeing conditions or weather, or other technical factors.
3. The signal should be integrated for four half-rotations of the SOT polarization modulator (3.2 seconds).
4. There should be no binning along the slit direction, and the data should be digitized for every step of the slit scanner.
5. Single-sided data will be sufficient.
6. Program a rapid sequence of short maps (about 10-15” wide) covering a well-developed sunspot umbra. A map of 90 slit scan steps would cover about 13

arcsec in about 5 minutes.
7. Maps should be repeated continuously during the GREGOR observation period.
8. The observations may be windowed along the slit to a length of 81” (512 CCD pixels) in order restrict the observations to the immediate vicinity of the sunspot. This length is long enough to properly sense and correct for the internal thermal drift of the SP.
9. Before or after the series of short scans a quick scan of the entire target (full sunspot) is desirable for alignment purposes. This scan can be done binning along the slit direction.

EIS Requests:

None.

XRT Requests:

None.

IRIS Requests:

IRIS observations will be obtained only if IRIS scheduling permits. If IRIS is unavailable for the initial observing run in late August 2016, observations will proceed with Hinode and GREGOR only. The IRIS observing program should have a faster cadence than that of Hinode or GRIS. The IRIS field-of-view will be narrower than that of Hinode or GRIS in order to have a repeat cadence short enough to capture rapid dynamic events in the chromosphere. The spacecraft should be rotated such that the slit is aligned with the N-S direction (parallel to the Hinode slit). IRIS spectra will be optimized for chromospheric lines, but will include higher temperature lines as well. We select the medium line list (C II, Si IV, Mg II h and k, two of the Mg II triplet lines around 2798Å). Of greatest interest for this study are the central emission peaks of the Mg II h and k lines. They are expected to have intensities comparable to the line core intensities in the quiet Sun. Slit jaw images indicating the slit position will be obtained at the following wavelengths: 1400, 1330, 2796, and 2832Å. These images will provide context for the spectra and facilitate coalignment with the other instruments. A probable IRIS program is 3620104026 having 8 steps of the slit with 0.33 arcsec spacing and 2 second integration, covering an area 2.32 x 60 arcsec. The repeat time for this program is 25 s.

Additional instrument coordination:

Ground-based observations will be carried out using the GREGOR Infrared Spectrograph (GRIS) at the German GREGOR telescope on Tenerife. The GRIS has a proven ability for high-resolution observations, approaching diffraction-limited performance for the 1.5m GREGOR telescope (~0.35” at 1565 nm, as

compared to 0.3” for Hinode at 630 nm), thanks to reduced seeing in the infrared relative to the visible, and a very stable image quality when used with the GREGOR adaptive optics instrumentation. We will use the newly-installed image de-rotator to align the slit along the N-S direction during GRIS observations. Cadence and field-of-view of the GRIS observations will be closely matched to those of Hinode SOT/SP. Co-proposer Juan Borrero will be present at the GREGOR telescope and will be responsible for managing the coordinated observations there.

Previous HOP information:

HOP 79. Lites is a co-PI of the ongoing HOP 79 irradiance program. In addition to numerous oral presentations, Lites has published the following work using this extensive data set:

B. W. Lites, R. Centeno, and S. W. McIntosh, 2014: “The Solar Cycle Dependence of the Weak Internetwork Flux”, PASJ, 66 (SP1), S4.

IHOP 313. “A Search Chromospheric Manifestation of Ubiquitous Photospheric Jets”
This IHOP was approved recently and observations are ongoing. Successful Hinode/IRIS observations have been obtained.

Additional Remarks: